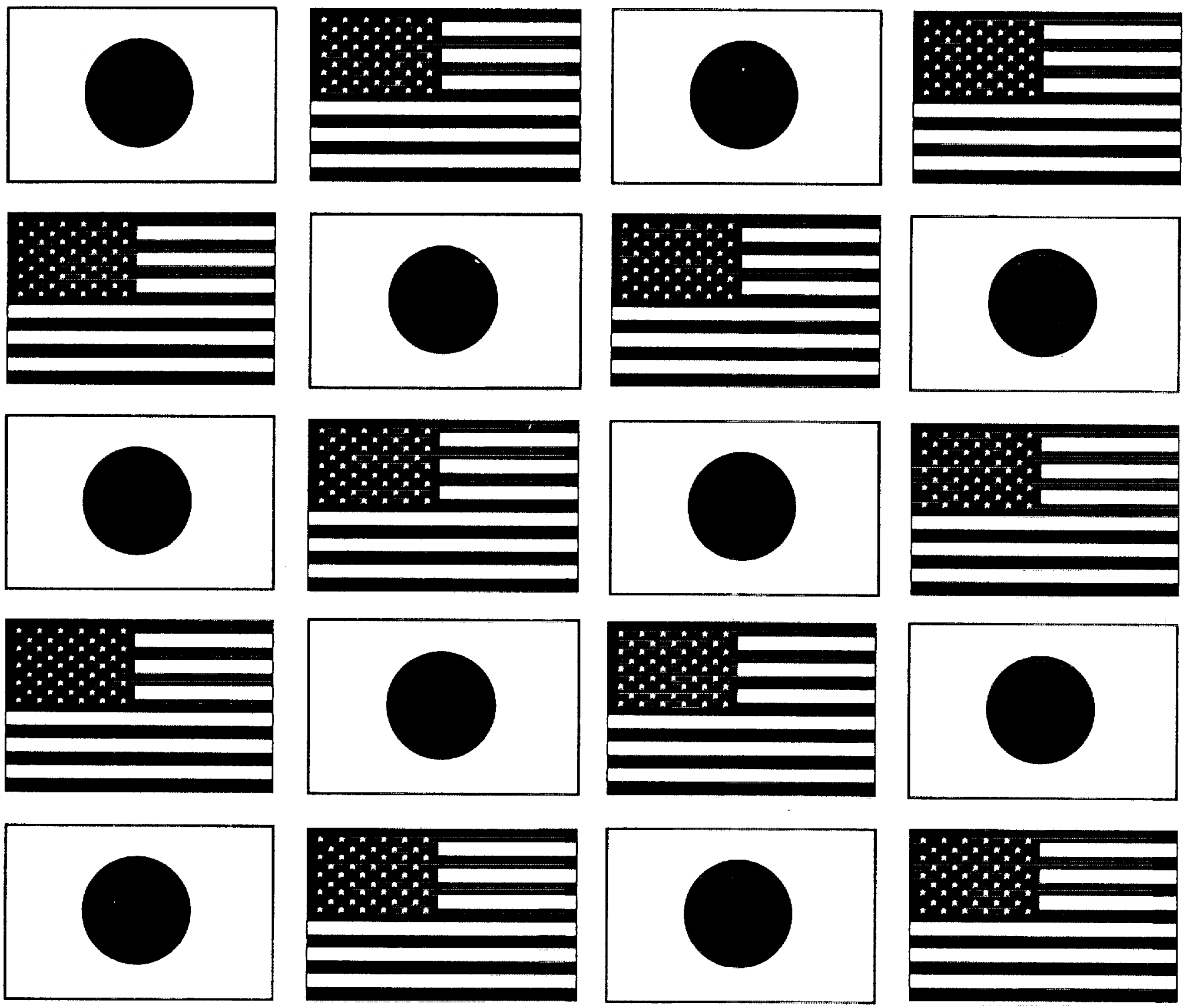
Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

NIST SP 931



U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

Wind and Seismic Effects

NIST SP 931

PROCEEDINGS OF THE 30TH JOINT MEETING OF THE U.S.-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES PANEL ON WIND AND SEISMIC EFFECTS

Issued August 1998

Noel J. Raufaste
EDITOR

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

TECHNOLOGY ADMINISTRATION
Gary R. Bachula, Acting Under Secretary for Technology

National Institute of Standards and Technology
Raymond G. Kammer, Director

SUMMARY of JOINT COOPERATIVE RESEARCH PROGRAMS

U.S.-Japan Cooperative Earthquake Engineering Research Program on Composite and Hybrid Structures - Current Status of Japan Side Research -

by

Isao Nishiyama *1, Hiroyuki Yamanouchi *2 and Hisahiro Hiraishi *3

ABSTRACT

The U.S.-Japan Cooperative Earthquake Engineering Research Program started in 1979 following the recommendations as outlined in the final report of the U.S.-Japan Planning Group for the program (Ref.1). The overall objective of the total program is to improve seismic safety practices in both countries through cooperative studies to determine the relationship among full-scale tests, small-scale tests, component tests, and related analytical and design implication studies. A five-year research program on Composite and Hybrid Structures was recommended to start in 1993 fiscal as the Phase 5 based on a number of technical meetings between the U.S. and Japan (Ref.2).

Because of diverse and broad scope of the subject area, the research program was organized into the following four groups: Concrete Filled Tube Column Systems; Reinforced Concrete (RC) and Steel Reinforced Concrete (SRC) Column Systems; RC / SRC Wall Systems; and New Materials, Elements and Systems. In addition to the objectives of the total program, Phase 5 aimed at (1) developing design guidelines (for a unified code development) for typical composite and hybrid structures, and (2) developing new and innovative composite structural elements and hybrid systems using advanced new materials and / or devices.

Japan side has just completed his assignment of the cooperative research work in the fiscal year of 1997. This report presents the outlines of the research conducted during five years and the general contents of the proposed draft guidelines.

KEYWORDS:
composite and hybrid structures; concrete filled tube column systems; reinforced concrete and steel reinforced concrete column systems; RC/SRC wall systems; new materials, elements and systems; outline of research results; proposed draft guidelines.

1. RESEARCH RESULTS ON CFT

1.1 Basic Research Plan

There are many experimental and analytical studies on concrete filled tube column (CFT) systems which are reported in technical journals. First, the strength and ductility of the CFT systems are predicted by processing these existing data. Secondly, the effectiveness of these predictions is verified by supplementary experimental studies. As the materials' strengths in use are quickly increasing, wide range of structural steel strength and concrete strength are considered to verify the applicability of the predictions. Finally, draft design guidelines are developed.

1.2 Research Items and Results

(1) Database

Test data of CFT columns and beam-columns were collected from the Japanese literature published in 1971 through 1995, and a database was developed. A total of 786 test data (test specimens) were found: 501 square CFT and 285 circular CFT. A database for the tests of connections between CFT column and steel beam was also prepared. Column bases and connections between CFT frame and brace are also important structural elements of CFT system, but however very few test data were available so far in Japan.

---

* 1 Head, Housing Construction Division, Production Engineering Department, Building Research Institute (BRI), Ministry of Construction (MOC), Tachihara-1, Tsukuba, Ibaraki, 305-0802, Japan.
* 2 Director, Codes and Evaluation Research Center, BRI, MOC.
* 3 Director, Structural Engineering Department, BRI, MOC.

(2) Trial Design of Theme Structure

Structural designs of 10, 24 and 40 storied CFT moment frame buildings and CFT dual system buildings were carried out on the theme structure shown in Fig.1. In these structural design, CFT member strengths were calculated based on the simple (generalized) superposing method proposed in the AIJ-SRC standards (Ref.3). The buildings with the same floor plan were also designed as pure steel frames.

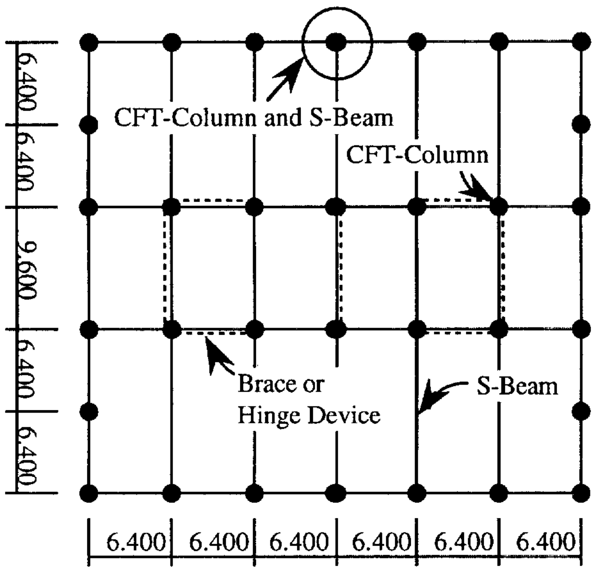


Figure 1 Floor Plan of Theme Structure on CFT

The total amount of structural steel, which is the index for estimating the economy of buildings, used for CFT buildings was compared with that used for pure steel buildings. In this comparison, CFT showed advantages over pure steel especially for higher buildings. The economical difference in CFT buildings with / without bracings was not large. It was because that the weight of bracings and the weight increase in the braced bay frame members compensated with the weight reduction of other frames which carried less horizontal force.

The modified plans which have 16 or 24 columns in each story, which were expected to show more advantages by CFT columns, were also investigated.

(3) Experimental and Analytical Study

The objectives of the experimental study are to evaluate the synergistic effects of structural steel tube and filled concrete and to evaluate stress transfer mechanisms in beam-to-column connections. So as to clarify these problems, four test programs were planned with several study parameters.

a) Experiments
  1) stub-column tests
  2) stub-column eccentric loading tests
  3) beam-column tests
  4) beam-to-column connection tests

b) Study Parameters
  1) tube shapes (rectangular, circular)
  2) tube strengths (400, 600, 800 MPa)
  3) width-to-thickness ratio
     (FA, FC, FD-rank* 1)
  4) concrete strengths (20, 40, 80-103 MPa)
  5) connection details (diaphragm, etc.)

----

*1 FA-rank of width-to-thickness ratio means that large member ductility is expected thanks to its compact section. FC-rank means that it can at least assure the yield strength of the member without deterioration. The width-to-thickness ratio of FD-rank is chosen as 1.5 times of that of FC-rank.

133 stub-column tests on rectangular (B=100-324mm) or circular (D=108-450mm) sections were completed. As the dimensions of the selected specimens were relatively large, and material strengths of structural steel tube (σy=400-780N/mm2) and concrete infill (Fc=20-103N/mm2) were also large, the maximum test strength reached 1,400tonf (13.72MN). As for the stub-column eccentric loading tests, 80 specimens were completed. From these test results, flexural moment (M) versus axial force (N) interaction of CFT section was obtained. The analytical M-N interaction estimated on the basis of the proposed stress versus strain models for concrete infill and steel tube considering synergetic effects well agreed with the test results.

As for the beam-column tests, 20 rectangular and 13 circular specimens were tested. Most of the specimens (16 for rectangular and 9 for circular sections) were tested under the constant axial thrust of 40% of compressive yield strength and others (4 specimens each for rectangular and circular sections) were tested under varying axial thrust of 70% of compressive yield strength and 30% of tensile yield strength. The structural steel strengths (400, 600, 800MPa), concrete strengths (40, 90MPa) and width-to-thickness ratios (FA, FC-rank) were selected as test parameters. As for rectangular sections, 4 specimens (constant axial thrust) were loaded in the direction of the plane which inclined 22.5 or 45 degrees from the axes of side plates. Fairly good agreements both in restoring force and axial shortening characteristics were obtained between test results and analytical ones, in which the proposed models for concrete infill and steel tube from stub-column concentric and eccentric tests were adopted with arbitrary selected hinge length. Inelastic 3D-FEM analyses were also carried out to see the stress flow (distribution) in the CFT beam-columns.

11 beam-to-column connection specimens were tested. Ten of them were one-way frame specimens (eight of them were tested with constant column axial force of 20% of compressive yield strength and two were tested with varying axial force between 70% of compressive yield strength and 30% of tensile yield strength) and the rest was the two-way frame specimen. Test results showed quite stable restoring force characteristics. The maximum shear strengths of the beam-to-column connections were well above the maximum panel shear strength proposed by AIJ-SRC (Ref.3). The recommended maximum panel shear strength proposed by AIJ-Steel Tube (Ref.4) coincided with the lower bound of the test results.

A slightly detailed test results and analytical studies on stub-columns, beam-columns and beam-to-column connections were summarized in Ref.5 and Ref.6.

(4) Empirical Study on Ductility

As for the strength of beam-columns, the analytical evaluation was quite satisfactory. However, the analytical evaluation on the ductility of beam-columns looked not promising, as the selection of the hinge length was arbitrary. Therefore, the empirical formulation for the ductility of beam-columns was tried both for rectangular and circular sections using existing test results. Empirical formulas taking into account the factors of axial force, the width-to-thickness ratio of steel tube and the strength of concrete infill were proposed for rectangular and circular sections, respectively.

As shown in Fig.2, the envelop of the shear force versus deflection relationship of the beam-column shown by OABC, where O is the origin, A is the yield strength, B is the maximum strength and C is the deteriorating curve, is simply characterized by OAB'B", where B' is the 95% pre-maximum strength point and B" is the 95% post-maximum one. From the empirical study, B' was given as the stiffness reduction factor in comparison with equivalent elastic stiffness and B" was estimated as the deformation capacity.

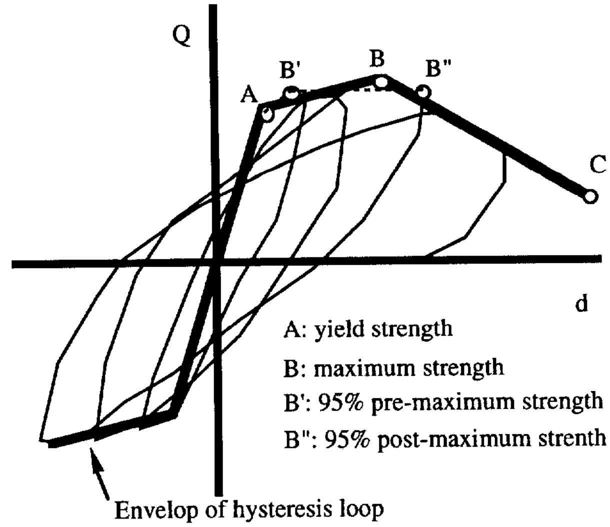


Figure 2 Envelop of Hysteresis Loop of CFT Beam-Columns

(5) Design Guidelines

Any of the structural design standards used in Japan do not contain provisions concerning the structural characteristic factor Ds (Rw in the U.S.) of CFT structures, which is necessary to calculate the required value of the lateral load resisting capacity of the story. Under this circumstance, Japanese working group for CFT systems tried to develop guidelines to the structural design of CFT systems, which contain the following items: i) formulas to evaluate strength, deformation capacity and Ds of CFT column considering the effects of confined concrete, local buckling, axial force and biaxial bending, ii) design formulas for diaphragm and shear panel of the beam-to-column connection, iii) modeling of restoring-force characteristics of column, connection and overall CFT system, and iv) method of concreting, concrete mixture and material tests at site.

Table 1 shows the tentative contents of the draft guidelines for the design of CFT column system.

Table 1 Draft CFT Design Guidelines

1. Introduction
   - 1.1 Structural characteristics of CFT column system
   - 1.2 State-of-the-art of research on CFT
   - 1.3 Research carried under U.S.-Japan Program
   - 1.4 Contents
2. Basic seismic design concept of CFT column system
   - 2.1 Basic seismic design concept and scope of application
   - 2.2 Seismic design method based on current method
   - 2.3 Seismic design method based on performance criteria

3. Behavior and design of CFT member
   3.1 General
   3.2 Behavior of CFT short column under concentric compression force
   3.3 Behavior of CFT short column under combined compression force and bending moment
   3.4 Behavior of CFT beam-column
   3.5 Design of CFT column
4. Behavior and design of CFT joints
   4.1 Behavior of CFT column to steel beam connection panel
   4.2 Design of CFT column to steel beam connection
   4.3 Design of brace connection
   4.4 Design of CFT column bases
5. Construction of CFT column system
   5.1 Steel tube
   5.2 Concrete infill
6. Example of trial design
Appendix 1. Trial design of CFT column system
Appendix 2. Test specimens carried under U.S.-Japan Program

---

2. RESEARCH RESULTS ON RCS

2.1 General

In Japan, a great number of beam-to-column sub-assemblage tests on RCS (reinforced concrete column and structural steel beam) systems have been conducted. However, the variations of the joint details are quite wide and so the test results have not been thoroughly investigated yet. Therefore, these existing test results are first compiled in a common format as a database. Then, the joint panel shear strength and ductility are investigated. In this consideration, the joint details are classified into through column type and through beam type.

As the existing test data are partial to interior through beam type joints, necessary exterior joint tests and through column type joint tests are planned. A basic study to investigate the stress transfer in the joint is also planned. In Japan, two-way frame system is more common, so 3D joint tests are planned. Frame test is also planned so as to increase the accuracy of the evaluation of the strength and ductility. Inelastic 3D finite element analyses are also planned to more precisely understand the behavior of the joints. Finally, draft design guidelines is developed.

2.2 Research Items And Results

(1) Review and Database

A total of 436 experimental data was included into a database, in which the information of about 160 items such as generals, the details of columns, beams and joints, experimental results and so on is written for each test. The collected test data are sort into 17 typical details for through beam type joints and 13 for through column type joints based on the types of reinforcing details. The data are also classified into 1) panel shear yielded data and 2) others.

Panel shear yielded data were used to verify the accuracy of the existing design formulas (maximum strength) for each typical details of the RCS connections. Adding the test data produced by the U.S.-Japan program, a better panel shear strength design formula was proposed by Eq.1.

$$Qp=Qw+Qf+Qh+Qc \qquad (1)$$

where,

$Qw=C1*Aw*{}_s\tau wy$
$Qf=0.5*Af*{}_s\tau fy$
$Qh=0.25*Pw*\sigma wy*Bc*mcd$
$Qc=0.4*C2*C3*Bc*Dc*0.1*{}_c\sigma b*j\delta$

Aw: sectional area of web plate
$_s\tau wy$: shear yield stress of web plate
Af: sectional area of web of cover plate
$_s\tau fy$: shear yield stress of cover plate
Pw: shear reinforcement ratio
σwy: yield stress of shear reinforcement
Bc: width of column
mcd: central distance between external reinforcements
Bc: column width
Dc: column depth
$_c\sigma b$: concrete compressive strength
$j\delta$: joint panel shape factor (=3 for +, 2 for T, and 1 for L joints)
C1: 0.8 for without FBP (face bearing plate) and 0.9 for with FBP
C2: 0.8 for without FBP and cover plate; 1.0 for with FBP or cover plate (prototype); 1.1 for prototype with extended FBP, or with outer side small column, or with inner side band plate; 1.5 for prototype with outer side band plate or with FBP + vertical rebar, or for diagonal stiffener; 1.6 for diagonal stiffener + wide FBP, or diaphragm.
C3: 0.9 for without transverse beam and 1.0 for with transverse beam.

The displacement information was used to estimate the shear force versus shear deformation relation of the joint panel.

(2) Trial Design of Theme Structure

6 and 12 story building frames were designed by the current Japanese design standards (Ref.3 &

Ref.7), whose floor plan is identical to Fig.1. The allowable stress design method was used with the static lateral forces corresponding to the base shear force coefficients of 0.918 and 0.133 for the 6 and 12 story buildings, respectively. Time history analyses using the equivalent multi-mass shear system for four recorded ground motions with 50 cm/sec of velocity amplitude were also conducted in which the hysteresis model was assumed by normal tri-linear with the monotonic envelop obtained by static pushover analysis. The maximum story drift and the maximum ductility ratio of the designed building frames were studied.

The designed buildings are also utilized to further investigate the realization of the proposed design guidelines from the practical view points.

(3) Beam-To-Column Connection

a) Stress Transfer Mechanism Study

The shear strength of the joint panel is thought to be estimated as the sum of the shear strengths of inner concrete, outer concrete, web of the structural steel and hoops. However, the contribution of outer concrete on the shear strength is quite doubtful as it is not known how the shear stress is transferred between inner and outer parts. So as to make clear the stress transfer mechanism, several sophisticated experiments were carried out.

b) Through Column Type Joint Tests

Ten specimens for interior beam-to-column connections were tested. In these tests, the effects of vertical stiffeners and the cover plates were investigated. These test results were useful for developing design formula for panel shear strength. The detailed test results are shown in Ref.8.

c) T- and L-Shaped Joint Tests

Fifteen beam-to-column connection specimens were tested to make clear the effects of the geometry (cruciform, T and L) of the joints. Here, the joint details of the through beam type with FBP, extended FBP, cover plate and band plate are all included. The through column type is also considered. Through these experiments and 3D-FEM analyses, the shape factors for cruciform shaped joint, T-shaped one and L-shaped one are evaluated as 3.0, 2.4 and 1.4, respectively. However, in the proposed design guidelines, the traditional shape factors as 3.0, 2.0 and 1.0 are adopted for practical simplification with safer side decision. The detailed test results are shown in Ref.8.

d) 3D Joint Tests

So as to see the inelastic behavior of beam-to-column connections under two directional loading, four 3D joint test specimens were constructed. Three of them are through column type with the identical shape and one is through beam type. One of the three identical through column joints was loaded in the direction of the frame (beam) in an ordinary manner. Second one was loaded in the direction of 45 degrees with respect to the axis of the frame. The third one was loaded following a circle shaped orbit. The strength and restoring force characteristics of the first and second specimens were quite resemble each other and the effect of loading direction can be considered negligible. However, the circle orbit loading largely reduced the strength. This effect was not included in the proposed design guidelines, which will be the future problem. The detailed test results are presented in Ref.9.

(4) Frame Test

So as to understand the overall inelastic behavior and required ductility in each structural elements of RCS frame, a two story (1.35m in story height) and two bay (2.1m in beam span) frame specimen was tested. The frame was designed as weak joint panel. The test results showed fairly good ductility, but the hysteresis loop showed pinched.

(5) 3D-FEM Analyses

Elastic and inelastic behavioral characteristics of bond and friction between concrete and steel were investigated by fundamental experiments. The test results were reflected to modify the constitutive models for the inelastic 3D-FEM program. Analytically obtained monotonic load versus deflection relationships were compared with the envelops of the cyclic behaviors of beam-to-column connections with excellent agreements, which verified the effectiveness of 3D-FEM analyses. The 3D-FEM analyses also gave us better understanding of the stress distribution in the beam-to-column connection. This analytical method was also applied to 3D-joint test and frame test and fairly good results were obtained. The detailed analytical results are shown in Ref.8.

3D-FEM analyses will be continued to complement data on the structural performance of RCS connections out of the extent of test data and to further improve the shear design formulas of RCS connections.

(6) Equivalent Damping of Joints and Frames

Equivalent viscous damping of 15 beam-to-column connections and 4 frames was calculated at each displacement amplitudes. The estimated damping was summarized as follows; i) Beam hinging specimens showed the largest damping and it reached 40% at the large displacement amplitude. ii) Column failure or bearing failure specimens showed the least damping and it was about 10% even at the large displacement. amplitude. iii) Joint panel shear yielding specimens showed intermediate damping between 10-20% and the cover plate improved the energy dissipation capacity.

(7) Draft RCS Design Guidelines

In recent years, a large number of RCS connection details have been developed and applied to the real construction practices. However, many of the new connection details and systems developed are not covered by the existing standards, and thus the establishment of original design procedures for RCS connections and systems are urgently needed in Japan.

Japanese working group for RCS systems developed draft design guidelines for RCS systems, which contained the following items: i) formula to evaluate panel shear strength, ii) yield mechanisms to be recommended and how to realize the intended mechanism, iii) modeling of restoring force characteristics of beam-to-column connections, and iv) fabrication and construction method.

Table 2 shows the tentative contents of the draft guidelines for the design of RCS system.

Table 2 RCS Draft Guidelines

Preface
Part 1: Draft design guidelines
1. General
   1.1 Scope of application
   1.2 Terminology
   1.3 Notations
   1.4 Related codes and standards
2. Materials
   2.1 Kind and quality of materials
   2.2 Material constant
   2.3 Allowable stress and material strength
3. Structural design
   3.1 Fundamentals for structural planning
   3.2 Fundamentals for panel design and details
   3.3 Design methods
   3.4 Method based on current practice
   3.5 Method based on performance criteria
   3.6 Design example
4. Fabrication and Construction
5. Example of Construction

Part 2: Technical Information
1. Database
   1.1 Introduction
   1.2 Profile of database
   1.3 Investigation of existing shear strength design formulas
   1.4 Proposed design formula
   1.5 Proposed skeleton model
2. Experimental and Analytical Results done by U.S.-Japan Program
   2.1 Stress transfer in the joint panel
   2.2 Behavior of through beam type joint
   2.3 Behavior of interior through column type joint
   2.4 Behavior of exterior joint
   2.5 Behavior of 3D joint
   2.6 Behavior of frame
   2.7 Inelastic 3D-FEM analysis
   2.8 Equivalent damping of RCS joints and frame

---

3. RESEARCH ON HWS

3.1 General

The structural system of core wall with exterior steel frame is not common in Japan and its design method is not established yet. So, six, twelve and twenty-four storied theme structures were preliminary designed. According to the preliminary design, six storied model was considered to be designed just depending on the large shear strength of walls. Twenty-four storied model needed hat truss (and belt truss) to reduce large overturning moment induced at the foot of the coupled shear walls, which made the development of general design procedure rather difficult. Therefore, twelve storied theme structure was first selected and the design problem was picked up. Then, the design implication is expanded into much higher or lower systems. The rationality of the designed system is verified through the analytical and experimental studies.

3.2 Research Items And Results

(1) Trial Design of Theme Structure

First, twelve story model building (see Fig.3) was designed on the basis of the general design concept (Ref.7). The strength of the designed building was too large to be investigated as the target structure to be developed. Then, the building was revised considering the design concept for the coupled-shear wall in New Zealand (Ref.10). In New Zealand practice, earthquake load is distributed to each wall according to the overturning moment ratio carried by boundary beams. As the building still had large overstrength, the reinforcements in the core walls were intentionally reduced to reach reasonable strength level, 35 percent as the base shear coefficient. The final designed building was investigated whether it performed well or not under the seismic effects through the dynamic inelastic analyses using fish-bone model or frame model.

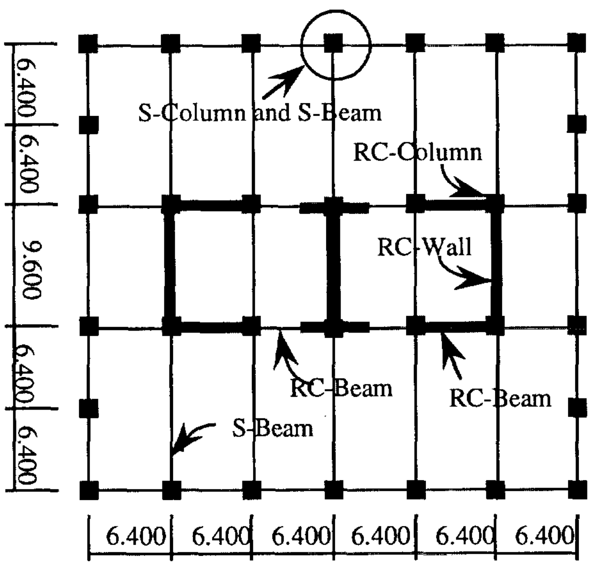


Figure 3 Floor Plan of Theme Structure on HWS

(2) Coupled-Shear Wall Test

One-third scale model of 12 storied coupled-shear wall test was carried out. During the test, the forces acting in each member was measured so as to understand the force re-distribution in the coupled-shear walls and boundary beams for design purpose. For this purpose, load cells were installed into all boundary beams. The coupled-shear walls showed very stable hysteresis loops until 1/67 radian in drift index. From the readings of the load cells, it was observed that the boundary beams act like wedges inserted between walls after they cracked and expanded in length. These test results were investigated by FEM and MS (multi spring) model analyses. The detailed test results and some analytical studies were discussed in Ref.11 and Ref.12.

(3) T- and L-Shape Shear Wall Test

To understand the stiffness, strength and deformability of 3D-wall is essential for the design implication to HWS systems. Three one-third scale T-shaped shear wall specimens without boundary columns, which represented the walls of the lowest story of the 12 storied prototype HWS system, were conducted. In these tests, the shear force and flexural moment with different moment-to-shear ratios were applied with varying axial forces.

Large axial force was expected at the corner of the 3D-wall of lowest story when two directional seismic force affected on the HWS system. Then, the ductility of the corner part of the wall depended much on its confinement. Therefore, four L-shaped shear walls varying their confinement level were tested with large axial force. These test data were utilized to develop hysteresis model of 3D-walls.

The detailed test results were discussed in Ref.13.

(4) Theoretical Study

Theoretical investigation was carried on the dynamic behavior of 3D HWS under the bi-directional earthquake motion, in order to establish a rational mathematical model in view of the experimental results, and the fluctuation of shear forces acting on dynamically-behaving rigid walls and flexible steel frames, to determine the design shear force for HWS.

(5) Literature Survey

About eighty papers on boundary beams and thirty papers on RC wall to steel beam connections were surveyed. As for the inelastic behavior of the boundary beams, the past analytical and experimental information was considered to be enough for design purpose. On the other hand as for the RC wall to steel beam connections, the isolated joint strength tests were found in the reports and no sub-assemblage tests were found. From this viewpoint, some verification test might be necessary for RC wall to steel beam connection. However, as the flexural stiffness of the steel beam with long span was very small and the rotational deformability of the joint itself was not so large, the experiment was not carried out.

(6) Design Guidelines

Seismic performance of each member in HWS differs significantly. Coupled walls and link beams may be damaged within a relatively small drift, while exterior steel frames will remain elastic at the limit drift of the walls. Design guidelines for HWS system should consider these different performance of each structural element. It is also indicated that the following items are important in the design of HWS, in addition to the design methodology of the coupled shear walls and link beams: design for diagonal loading, soil spring effect, seismic use of perimeter steel frame, confinement of compression wall, and method of energy dissipation.

Table 3 shows the tentative contents of the draft guidelines for the design of HWS system. The detailed explanation of the design concept is presented in Ref.13.

Table 3 HWS Draft Guidelines

Introduction
1. Scope of Application
   1.1 Structural components
   1.2 Scale and geometry of building
   1.3 Materials
2. Target Performance in Seismic Design
   2.1 Establishment of target performance
   2.2 Confirmation of target performance
3. Check of Target Performance
   3.1 Input ground motion
   3.2 Analytical methods
   3.3 Check of design criteria
4. Check of member performance
   4.1 Fundamentals for member performance
   4.2 Walls
   4.3 Boundary beams
   4.4 Exterior frames
   4.5 Steel beam to core wall connections
   4.6 Foundations

Appendix 1. Design examples
Appendix 2. References, Test report and Other
Appendix 3. Examples of Dynamic Analyses

4. RESEARCH RESULTS ON RFI

4.1 Feasibility Study

Following items were discussed as possible research topics: Fiber reinforced plastics (FRP), high-performance concrete (HPC), intelligent material, prestressed steel member, hinge device, mega-structure system, recycle element, fire-proofing material for CFT, and high-performance steel. Some hearing-type meetings with material manufacturers and general contractors were conducted with a view to study a possibility of above items as research topics of RFI, and FRP and HPC were selected for feasibility studies on effective use.

4.2 Research on FRP

The research program on effective utilization of FRP materials for composite and hybrid structures contained three research items as follows. These items were selected through the feasibility study on effective utilization of FRP.

a) Development of the evaluation method for high-performance FRP-RC panels.

b) Development of the effective repair and / or strengthening method by using FRP for existing RC members.

c) Feasibility study on the effective utilization of FRP to the electrical facilities.

The behaviors of FRP-RC panels of flat- and tube-types reinforced by 2-dimensional FRP reinforcements, under axial tension and compression, in-place flexure and shear and out-of-plane flexure were experimentally investigated. The flexural and shear behaviors and confinement of concrete of RC columns which were wrapped by FRP strand or FRP sheet / tape with resin for repairing and / or strengthening were also investigated. The application of FRP to the electrical facilities such as a power station, and structures that had to be sheltered from electrical noise was studied from the literature survey.

4.3 Research on HPC

There are few cooperative research between concrete makers and structural designers in Japan. The makers have many technologies but they don't know how to use it. On the other hands, designers have a few information about new technologies of concrete. But they have many hints about the idea of future concrete.

The main objective is to exchange the information of makers and structural designers to discuss about how to use effectively the concrete materials to the structural members and how will be the future concrete. Through the discussions, the following two topics were depicted.

a) Light weight concrete with high strength of which the specific gravity is imaged to be about 1.2 and 1.6, and the compressive strength of 30 and 60 MPa, respectively

b) Advanced concrete with high tensile strength and ductility of which the tensile strength is imaged from 30 to 200 MPa, and the tensile ductility from 1 to 10 %.

As for the light weight concrete, two kinds of imaged concrete were realized and several fundamental tests on bond strength and compressive strength were carried out.

As for the high tensile strength concrete, various types of fibers with mortal were tested and some of them showed high tensile strength and good compressive ductility. However, it was made clear that such performance was quite sensitive to the kind of fibers.

4.4 Technical Information

The research results can not be summarized as design guidelines but they can be used as technical information. Design guidelines will contain the items concerning the design, fabrication, construction and application of the advanced materials mentioned above, that is, FRP-RC panel element, FRP strand and sheet / tape for repairing and strengthening of existing RC members, FRP for electrical facilities, light weight concrete with high strength and concrete with high tensile strength and ductility.

5. SUMMARY

U.S.-Japan Cooperative Earthquake Engineering Research on Composite and Hybrid Structures initiated in 1993 fiscal as a five year program came to the final stage. This paper presents the outlines of the research results conducted during this five years and the general contents of the proposed draft guidelines by Japan side. Research results by the U.S. side which will come out in other two or three years shall be reflected to improve the design guidelines presented in this paper.

ACKNOWLEDGMENTS

The authors wish to express their great thanks to the Members of Japan Technical Coordinating Committee for their useful comments and suggestions to the development of design guidelines and / or technical information on CFT, RCS, HWS and RFI.

REFERENCES

1. "Recommendations for a U.S.-Japan Cooperative Research Program utilizing Large-Scale Testing Facilities", Report No. UCB / EERC 79-26, 1979.9.
2. "Recommendation for U.S.-Japan Cooperative Research Program -Phase 5 Composite and Hybrid Structures", Report No. UMCEE 92-29, 1992.11.
3. " Standards for Structural Calculation of Steel Reinforced Concrete Structures," Architectural Institute of Japan, 1987 revision.
4. " Recommendations for the Design and Fabrication of Tubular Structures in Steel," Architectural Institute of Japan, 1990 revision.
5. S. Morino, " An overview of U.S.-Japan Cooperative Earthquake Research Program on CFT column systems," SEWC' 98, July 19-23, 1998.
6. K. Sakino et al., " Experimental studies and design recommendations on concrete filled steel tubular columns -U.S.-Japan Cooperative Earthquake Research Program-," SEWC' 98, July 19-23, 1998.
7. " Structural Provisions for Buildings," Building Center of Japan, 1994.9. (in Japanese)
8. H. Noguchi et al., " Shear strength of beam-to-column connections in RCS system," SEWC' 98, July 19-23, 1998.
9. I. Nishiyama et al., " Bi-directional seismic response of reinforced concrete column and structural steel beam subassemblages," SEWC' 98, July 19-23, 1998.
10. T. Paulay and M. J. N. Priestley, " Seismic Design of Reinforced Concrete and Masonry Buildings," John Wiley & Sons, Inc.
11. M. Teshigawara et al., " Seismic test on 12-story coupled shear wall with flange walls," SEWC' 98, July 19-23, 1998.
12. M. Teshigawara et al., " Energy absorption mechanism and the fluctuation of shear force in the coupled shear walls," SEWC' 98, July 19-23, 1998.
13. T. Kabeyasawa et al., " Displacement-Based Design of Hybrid Core Wall System," SEWC' 98, July 19-23, 1998.